COMPARISON OF ARTHROPOD BIODIVERSITY BETWEEN CONVENTIONAL AND ALLEY-CROPPING SYSTEM IN OIL PALM PLANTATION IN RELATION TO MICROCLIMATIC AND VEGETATION STRUCTURES

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By

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Chairman : Badrul Azhar Bin Md Sharif, PhD
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Oil palm (*Elaeis guineensis*) is among the most rapidly expanding and cultivated crops due to high global demand for vegetable oils. Large areas of forest have been converted into oil palm plantations to meet the market demand, especially in Southeast Asia. This has caused biodiversity loss and induced climate change. The alley-cropping system has the potential to promote flora and faunal biodiversity, provide natural predation on pests, and improve microclimate features such as air temperature, ground temperature and higher humidity. This study determines the patterns of arthropod biodiversity, arthropod functional groups, vegetation structure and microclimate conditions with different oil palm agricultural practices. It compared arthropod biodiversity, arthropods predators and decomposers using pitfall traps in five alley-cropping treatments (pineapple, bamboo, black pepper, cacao, bactris), where oil palm is intercropped with another species with two monoculture oil palm treatments. We also compared microhabitat quality of vegetation structure such as vegetation cover for grass and non-grass and height for grass and non-grass using 1m x 1m quadrats and 2m x 5m quadrats. We also measure microclimate such as air temperature, relative humidity, light intensity and wind speed and soil conditions such as soil surface temperature, soil pH and soil moisture. A total of 50,155 arthropod individuals were recorded, representing 19 orders and 28 families of which 14 orders belonging to sub-phylum Insecta, three orders from Arachnida (Araneae; Acarinae; Scorpiones) and two orders from Microcoryphia (Chordeumatida; Geophilomorpha). This study found that the number of arthropod orders, families, abundance, and the number of predators and decomposers were significantly greater in alley-cropping farming plots than those in monoculture plots. This study found that the

vegetation structure was significantly greater in the alley-cropping system compared to the oil palm monoculture system. Similarly, this study found that the microclimate and soil condition improved significantly in the alley-cropping system than in the monoculture oil palm system. Moreover, this study found that black pepper crops and cacao crops were the best crop species to be implemented in the alley-cropping system due to having a lower temperature (33.19°C; 33.27°C), higher humidity (60.53%; 59.02%) and a richer vegetation structure compared to other crops. The findings from this study suggest that the alley-cropping system could become a key management strategy to improve biodiversity conservation, ecosystem services, vegetation structure and microclimate features within oil palm production landscapes. Furthermore, careful selection of crop species for intercropping with oil palm crops is important to aid in the preservation of variation of vegetation structure and improvement of microclimate features in the plantation.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Master Sains

PERBEZAAN KEPELBAGAIAN BIOLOGI ARTROPOD DI ANTARA SISTEM MONOKULTUR KELAPA SAWIT DAN SISTEM INTEGRASI TANAMAN BERLORONG DALAM LADANG KELAPA SAWIT DIKAITKAN DENGAN IKLIM MIKRO DAN STRUKTUR VEGETASI

Oleh

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Kelapa sawit (*Elaeis guineensis*) merupakan di antara tanaman yang paling berkembang dan ditanam kerana di atas permintaan yang tinggi dari peringkat global untuk hasilnya. kawasan hutan yang luas telah ditukarkan kepada ladang kelapa sawit untuk memenuhi permintaan ekonomi terutamanya di Asia Tenggara. Hal ini menyebabkan pengurangan biodiversiti dan menyebabkan perubahan iklim yang drastik. Sistem integrasi tanaman berlorong mempunyai potensi untuk mengembalikan biodiversiti flora dan fauna, mewujudkan rangkaian makanan di antara pemangsa dan serangga perosak, membaik pulih keadaan cuaca seperti suhu udara dan suhu tanah yang lebih baik dan kelembapan yang lebih tinggi. Misi kajian ini ialah untuk mengenal pasti biodiversiti arthropod, kumpulan berfungsi arthropod, struktur vegetasi dan keadaan iklim di dalam sistem agrikultur yang berbeza. Kajian ini membandingkan biodiversiti arthropod, arthropod pemangsa dan pengurai menggunakan perangkap cawan di antara lima sistem integrasi tanaman berlorong (nenas, buluh, lada hitam, koko, baktris) di mana kelapa sawit ditanam bersama spesis lain, bersama dua sistem monokultur kelapa sawit sahaja. Kajian ini uga membandingkan karakter habitat vegetasi struktur (vegetasi tanah untuk rumput dan bukan rumput dan tinggi vegetasi untuk rumput dan bukan rumput) menggunakan kuadrat 1m x 1m dan kuadrat 2m x 5m. Kami juga membandingkan kualiti iklim (suhu udara, kelembapan, intensiti cahaya dan kelajuan angin) dan keadaan tanah (suhu permukaan tanah, ph tanah dan kelembapan tanah). Sejumlah 50, 155 arthropod individu telah ditangkap, mewakili 19 order dan 28 famili di mana 14 order tergolong dalam sub-phylum Insecta, tiga order dari Arachnida (Araneae; Acarinae; Scorpiones) dan dua order dari Microcoryphia (Chordeumatida; Geophilomorpha). Kajian ini mendapati bilangan order, famili, individu dan bilangan arthropod pemangsa dan pengurai lebih tinggi di sistem integrasi tanaman berlorong dari sistem monokultur sahaja. Kajian ini juga mendapati struktur vegetasi lebih bagus di sistem integrasi tanaman berlorong. Tambahan pula, kajian ini uga mendapati keadaan iklim dan tanah yang lebih bagus di sistem integrasi tanaman berlorong dari sistem monokultur kelapa sawit. Selain itu, kajian ini mendapati lada hitam dan koko merupakan tanaman yang paling sesuai untuk ditanam bersama kelapa sawit kerana mereka mempunyai keadaan suhu (33.19°C; 33.27°C) dan kelembapan yang lebih baik (60.53%; 59.02%) serta struktur vegetasi yang lebih tinggi dari tanaman lain. Hasil dari kajian ini mencadangkan bahawa sistem integrasi tanaman berlorong boleh menjadi kunci strategi untuk membaik pulih biodiversiti, servis ekosistem, struktur vegetasi dan keadaan iklim di dalam ladang kelapa sawit. Tambahan lagi, pemilihan tanaman untuk diintegrasikan bersama kelapa sawit adalah penting bagi pemuliharaan struktur vegetasi dan pemulihan cuaca iklim di dalam ladang kelapa sawit.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

CPO	Crude palm oil
PKO	Palm kernel oil
POME	Palm oil mill effluent
EFB	Empty fruit bunches
MW	Mega Watt
LAI	Leaf area index
CBD	Convention on Biological Diversity
COP	Conference of the parties
MPOC	Malaysian Palm Oil Council
RSPO	Roundtable on Sustainable palm Oil
IPM	Integrated Pest Management
MSPO	Malaysian Sustainable Palm Oil Standard

CHAPTER 1

INTRODUCTION

1.1 General Review

Oil palm (*Elaeis guinensis*) is the most rapidly expanding cultivated crop in the tropics due to global demand for palm oil as edible oils, non-food products and used as a biofuel feedstock (Fitzherbert et al., 2008; Verheye, 2010). Palm oil is the highest vegetable oil exported and monopolises 60% of the global exports, surpassing other vegetable oil crops such as soybean oil (10%), Rapeseed oil (3%) and sunflower oil (4%) (Carter et al., 2007). Furthermore, palm oil is the highest vegetable oil produced globally since 2009 where it accounts for 34.0% of the world market, while soybean oil, rapeseed oil and sunflower oil had 27.0%, 16.2% and 9.8% of the world market (Teoh, 2010).

Malaysia and Indonesia are currently the largest palm oil producing countries dominating 80% of the world's palm oil production (Koh & Wilcove, 2008; Fitzherbert et al., 2008; Ng et al., 2012). The total oil palm planted in Malaysia recorded an increment of 1.3% from 5.74 million hectares in 2016 to 5.81 million hectares in 2017 (MPOB, 2018). The rapid expansion of oil palm plantations is causing deforestation, especially in tropical regions. This threatens biodiversity as tropical rainforests are home to many endemic and forest species and are the most carbon-rich place on Earth (Green et al., 2005; Koh, 2008; Wilcove & Koh, 2010). Numerous studies have shown that oil palm plantations comprised less avian, mammals and arthropod species compared to the natural forest (Senior et al., 2013; Fitzherbert et al., 2008; Petrenko et al., 2016; Hendrickx et al., 2007). Even though current research suggests that oil palm plantation can preserve a high number of species, these populations are distinct from those in natural forests especially concerning native species assemblages (Danielsen et al., 2009).

Moreover, climate change and environmental pollution due to fertiliser and pesticide or herbicide usage are effects of oil palm expansion (Wilcove & Koh, 2010). Lack of complexity of the understory vegetation coverage and canopy cover in oil palm plantations cause climate change by inducing hotter temperatures and drier humidity especially in young plantations (Tews et al., 2003; Schroth et al., 2004). Oil palm expansion increases greenhouse gases (CO2) emission, poor rainfall due to deforestation, the release of methane gas from mill effluent treatment and nitrous oxide (N2O) from the usage of nitrogen fertilisers (Corley & Tinker, 2016).

To apprehend this situation, oil palm growers have implemented several environmentally-friendly farming practices such as maintaining riparian trees along rivers, preserving forest patches within oil palm plantations, using biological pest control, zero burning and Integrated Pest Management (IPM) (Basiron, 2007; Verheye, 2010). Maintaining riparian reserves can provide wildlife corridors for the wildlife within the plantation. IPM is preferred for controlling pests rather than using pesticides. The application of biological control such as using barn owls to control rodent populations was very promising and can be used to replace chemical pesticide (Basiron, 2007). Zero burning practices have been applied to clear land to prevent pollution and damages to the environment from land clearing activities (Tan et al., 2009).

Agriculture sustainability, especially in oil palm plantations, is important as palm oil is the top most demanded vegetable oil globally. Therefore, oil palm crops need to be planted in a manner to prevent negative risks to the economy, society and environment (Basiron and Chan, 2006). Concerns of how oil palm expansion causes environmental effects led to the formation of the Roundtable on Sustainable Palm Oil (RSPO) in 2004 (Laurance et al., 2014). RSPO is a non-profit organisation to promote sustainable oil palm practices and providing RSPO-certified palm oil to the global market (Laurance et al., 2014). RSPO imposes principles and criteria which need to be followed by the stakeholders that focus on issues such as minimising the use of herbicides or pesticides, biodiversity loss, pollution, social and even legal concerns (RSPO, 2005). It promises the potential for healthier management and improved environmental performance of producers and palm oil users (Laurance et al., 2010).

1.2 Problem Statement

Oil palm expansion is the main threat to biodiversity especially in Southeast Asia as significant natural habitats are eradicated by land clearing activities (Myers et al., 2000). Tropical forest clearance causes disequilibrium in the ecology of forests. Moreover, oil palm plantations can only support low biodiversity with limited ecosystem functions and frequently changing extreme climates compared to natural forests (Fitzherbert et al., 2008). Even though oil palm plantations can preserve some flora and fauna, it can only provide refuge to a low number of wildlife and plants compared to natural forest areas (Foster et al., 2011). Most specialised species cannot withstand land changes and face extinction. Generalised species, however, can endure the changes in landscapes. Bruhl and Eltz (2010) found that ground-dwelling ant species were lower in oil palm plantations compared to natural forests. Furthermore, they found that most of the dominant species were non-forest species and invasive species (Bruhl and Eltz, 2010).

Land clearing to establish oil palm monoculture plantation greatly reduces the richness and diversity of specific arthropod taxa including beetles, moths and ants (Chung et al., 2000; Chey, 2006; Pfeiffer et al., 2008). This is due to a lack of microhabitat, fewer food sources available and climate changes within oil palm environments (Fayle et al., 2010). For example, having simplified understory vegetation can have negative effects on the population and interaction between organisms in the oil palm plantation. This relationship was reported in a study conducted by Spear et al. (2017) who observed the population and interaction between *Argyrodes miniaceus* (Araneae: Theridiidae) a cleptoprasitic spider with the host (Araneae: Nephilinae) spider reduced in simplified understory vegetation in oil palm plantations. Moreover, aquatic arthropods ecosystems are affected by oil palm expansion as it modified rivers and streams (Nepstad et al., 2008). Juen et al. (2016) found that modified streams or rivers found in oil palm plantations especially with scarce ground stream cover can only accommodate a small number of aquatic organisms.

Arthropods are beneficial components in an ecosystem as they provide valuable ecosystem services in agricultural areas. They play a major role in crop pollination by contributing to increasing crop yield, quality and higher profit as well as conserving time and space (Garibaldi et al., 2011). Furthermore, they act as biological predators and food source to higher predators in oil palm production landscapes (Fayle et al., 2010). Arthropods are recognised as playing a major role as decomposing by feeding on various types of plant detritus such as dead wood and leaf litter and aiding in nutrient and carbon cycling (Hooper et al., 2005). Besides that, arthropods can assist in seed dispersal especially in agriculture areas. Therefore, changes in the habitat can cause the loss of important functions of arthropods which would have a significant impact on the proper functioning of ecosystems (Hooper et al., 2005).

Forest conversion to oil palm monoculture plantations modifies habitat features dramatically and causes climate change. Large forest areas are cleared when establishing plantations causing significant loss of vegetation species during the process (Butler and Zhao, 2011). Oil palm monoculture plantations lack multi-complexity in vegetation structures such as sparse ground vegetation cover, the absence of multiple canopy strata and having the same aged trees with uniform plantation techniques (Corley & Tinker, 2003; Fischer & Lindenmayer, 2007; Chung et al., 2000). In addition, extreme climates in oil palm plantations such as unusually hot and dry conditions and lesser mean rainfall can threaten species populations (McCain and Colwell, 2011). For example, a study in Australia by Welbergen et al. (2008) showed that severe temperature cases eradicate whole populations of Australian flying-foxes (*Pteropus alecto* and *P. poliocephalus*). Extreme climates tend to have negative impacts on the species as the rate of fluctuation in the climate is much faster than species' capability to adjust to them physiologically or to migrate to new habitats with bearable conditions (Compton et al., 2007; Chen et al., 2011). Thus, the survival of species depends on whether they can adapt to the extreme weather or find refuge which can provide them with an optimum climate (Sears et al., 2011).

Nevertheless, oil palm monoculture plantation can accommodate a certain level of floral and faunal diversity even though it is significantly less compared to natural habitats (Azhar et al., 2011; Asmah et al., 2016; Ghazali et al., 2016). Preserving biodiversity is the key to providing ecosystem functions and creating sustainable agriculture practices (Foster et al., 2011; Dislich et al., 2016). Therefore, essential sustainable management is needed to reduce the negative impacts of oil palm expansion on the biodiversity. Alley-cropping system is an agricultural practice that integrates the main commercial crop cultivated with other commercial crops within an agricultural area (Gold & Garret, 2009). It has the potential to maintain biodiversity by providing habitats, food source, refuge and improved ecosystem services (Quinkenstein et al., 2009; Jose, 2012). Several studies conducted on the alley-cropping system cover on agroforestry crops such as cacao and banana plants (Harvey & Villalobos, 2007; Harvey et al., 2006) but limited empirical evidence supports implementing the alley-cropping system in large-scale oil palm monoculture plantations. As oil palm is now the most cultivated vegetable oil producer globally, its sound environmental management is essential.

1.3 Justification

This study provides insights into whether the alley-cropping system can help improve the biodiversity, especially in large-scale oil palm monoculture plantations. The findings showed that the alley-cropping system could improve arthropod biodiversity within the oil palm monoculture plantation. Arthropods are important components in the ecosystem as they provide various ecosystem services especially as pollinators and potential biological predators. Furthermore, the alley-cropping system aids in providing higher and much more complex habitat heterogeneity with enhanced microclimate conditions compared to conventional oil palm monoculture plantations. This is the first study to examine the effects of the alley-cropping system on arthropod populations in large-scale oil palm monoculture plantations. This research lays the groundwork for future research into answering questions that arise from implementing the alley-cropping system in oil palm monoculture plantations. Thus, the present study promises to offer a new wildlife-friendly mechanism for the stakeholders to improve oil palm management practices.

Oil palm monoculture plantations should be considered as supplementary biodiversity reservoirs and managed sustainably. Implementing eco-friendly farming approaches can have a positive impact on improving oil palm plantation surroundings. Arthropods are identified as biological indicators for assessing the health of an ecosystem. Evaluating the arthropod population can provide information on whether the alley-cropping system can preserve biodiversity more than the conventional monoculture oil palm system. In this study, an arthropod survey was conducted using the pitfall trap method. This study may support the hypothesis that the alley-cropping system contains higher arthropod populations and vegetation structure and that the microclimate is better than the conventional monoculture oil palm system. This study only focus on predation and decomposers as these two are among the major ecosystem services provided by arthropods related to feeding mechanisms and it is not feasible to focus on too many difference ecosystem services as it is time consuming and too much workload.

1.4 The Objectives of the Study

The main objective was to study the diversity of terrestrial arthropods in the agroforestry alley-cropping system in relation to microclimate and vegetation structure in large oil palm plantations. To achieve this, the study:

1. Compares the total number of arthropod orders, family and abundance observed between the conventional monoculture oil palm system and alley-cropping system.
2. Compares the predator and decomposer arthropod abundance between the conventional monoculture oil palm system and alley-cropping system.
3. Compares the habitat quality concerning vegetation structure, microclimate and soil characteristics between the conventional monoculture oil palm system and alley-cropping system.

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